US010094174B2

(12) **United States Patent**
**Jain et al.**

(10) **Patent No.: US 10,094,174 B2**
(45) **Date of Patent: *Oct. 9, 2018**

(54) **EARTH-BORING TOOLS INCLUDING PASSIVELY ADJUSTABLE, AGGRESSIVENESS-MODIFYING MEMBERS AND RELATED METHODS**

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( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 308 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/973,282**

(22) Filed: **Dec. 17, 2015**

(65) **Prior Publication Data**

US 2017/0175455 A1 Jun. 22, 2017
US 2018/0179826 A9 Jun. 28, 2018

**Related U.S. Application Data**

(63) Continuation-in-part of application No. 13/864,926, filed on Apr. 17, 2013, now Pat. No. 9,255,450.

(51) **Int. Cl.**
***E21B 10/62*** (2006.01)
***E21B 7/06*** (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC .............. ***E21B 10/62*** (2013.01); ***E21B 7/064*** (2013.01); ***E21B 10/20*** (2013.01); ***E21B 10/42*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC .... E21B 10/62; E21B 10/54; E21B 2010/622; E21B 7/064; E21B 10/32; E21B 10/322; E21B 10/325; E21B 10/34; E21B 10/345
See application file for complete search history.

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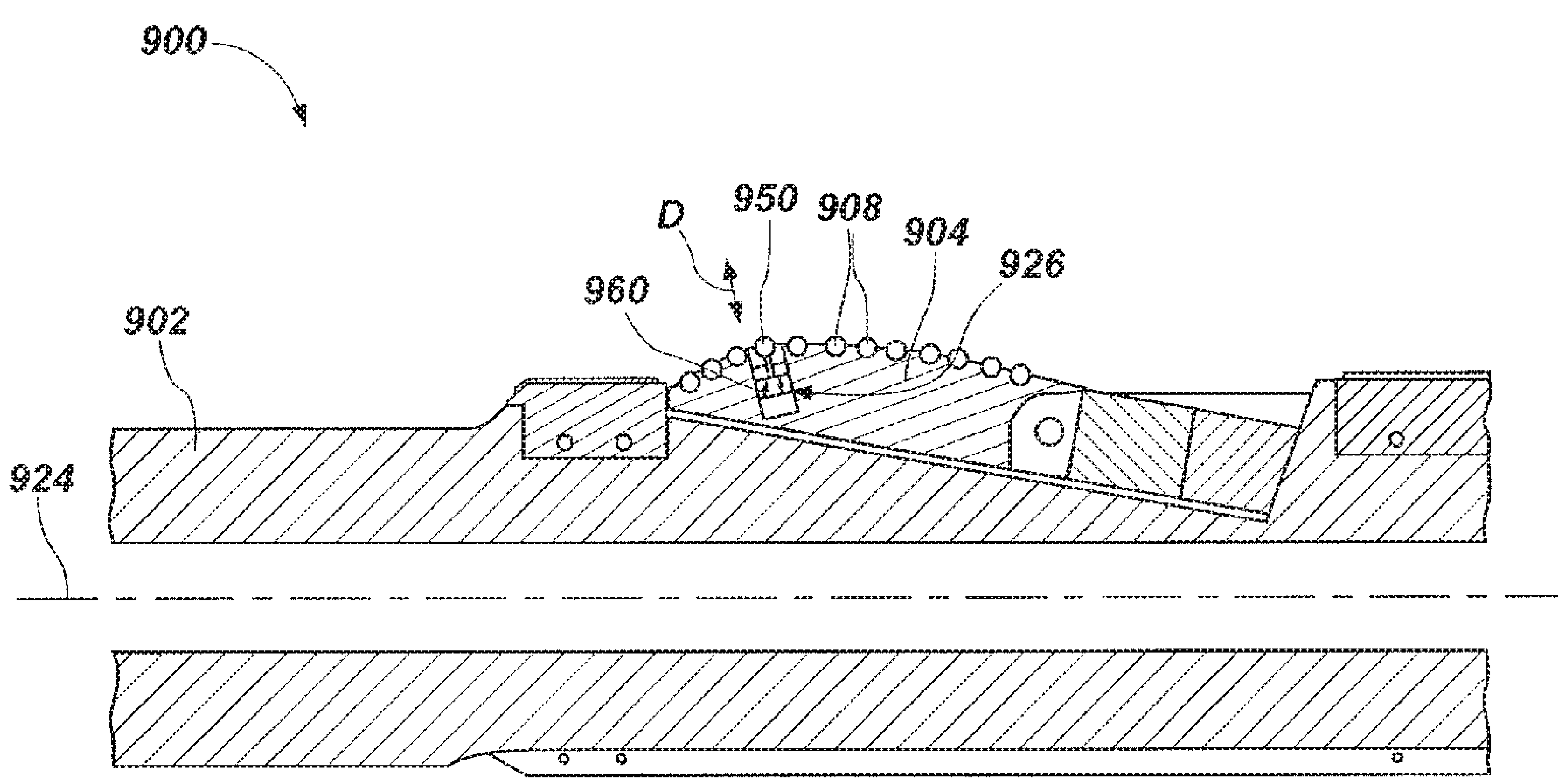
(57) **ABSTRACT**

Earth-boring tools may include a body and a passively adjustable, aggressiveness-modifying member secured to the body. The passively adjustable, aggressiveness-modifying member may be movable between a first position in which the earth-boring tool exhibits a first aggressiveness and a second position in which the earth-boring tool exhibits a second, different aggressiveness responsive to forces acting on the passively adjustable, aggressiveness-modifying member.

**17 Claims, 8 Drawing Sheets**



(51) **Int. Cl.**
***E21B 10/54*** (2006.01)
***E21B 10/20*** (2006.01)
***E21B 10/42*** (2006.01)
***E21B 17/10*** (2006.01)

(52) **U.S. Cl.**
CPC .......... ***E21B 10/54*** (2013.01); ***E21B 17/1092*** (2013.01); *E21B 2010/622* (2013.01)

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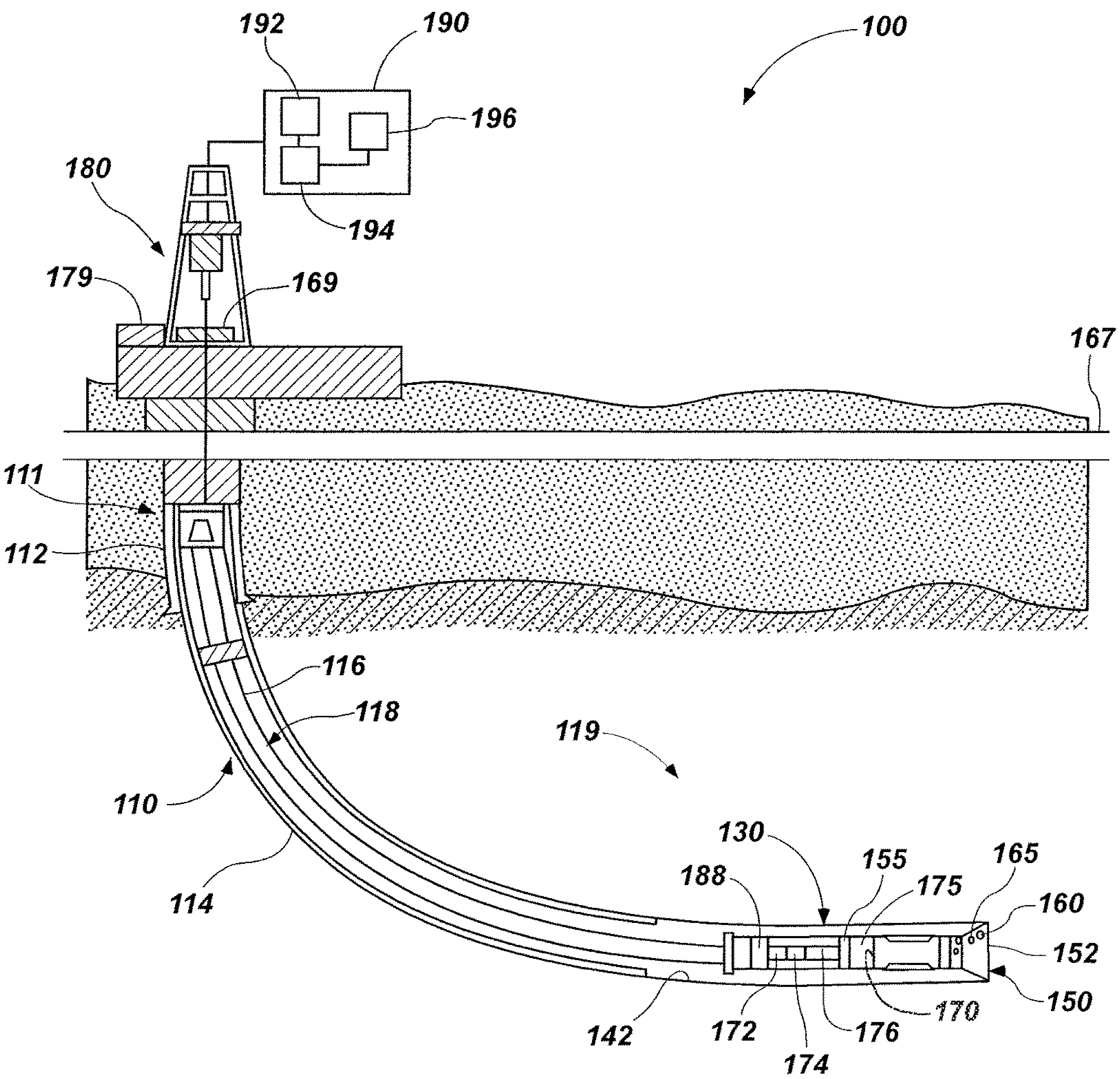
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FIG. 1

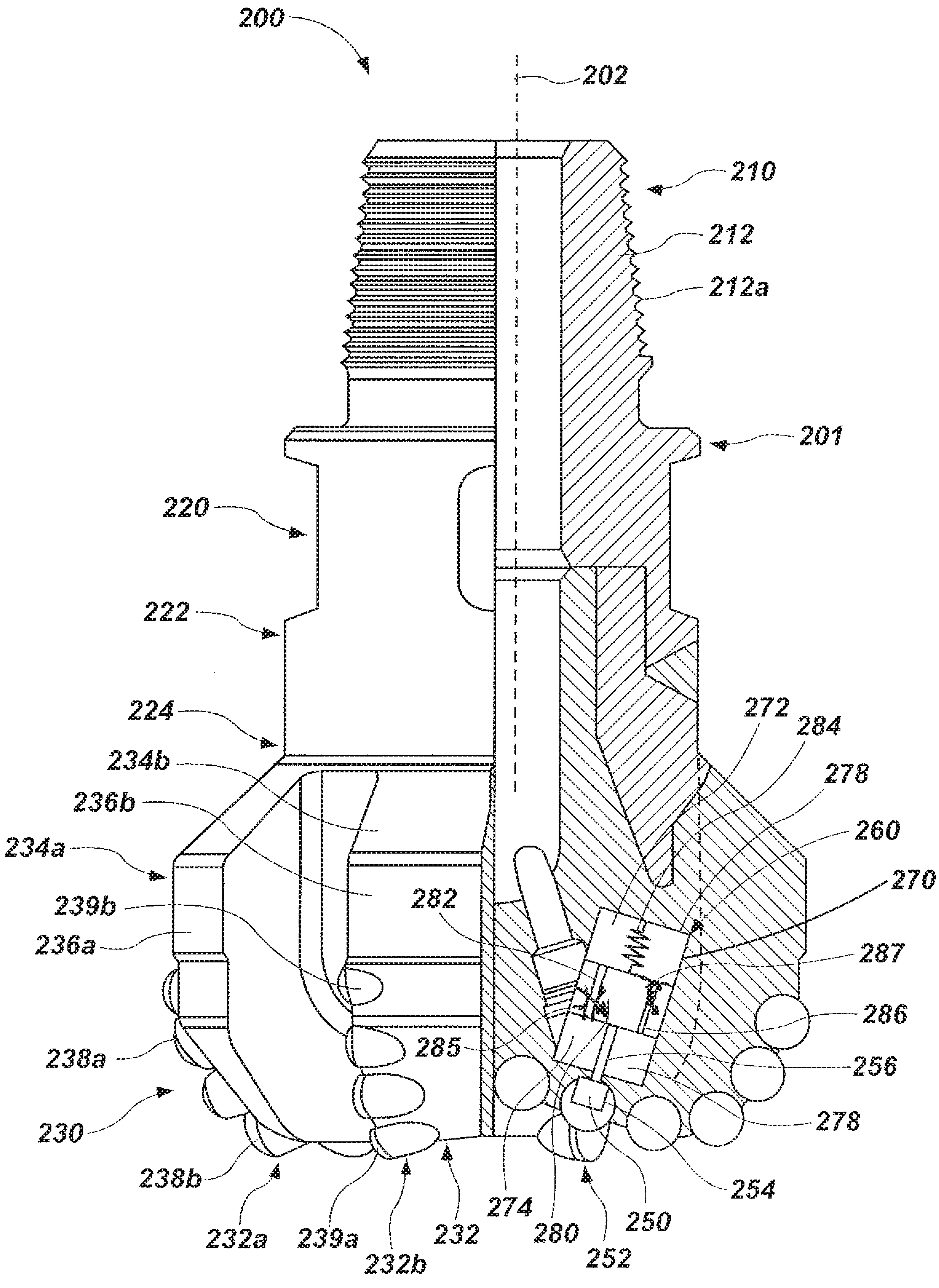
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FIG. 2

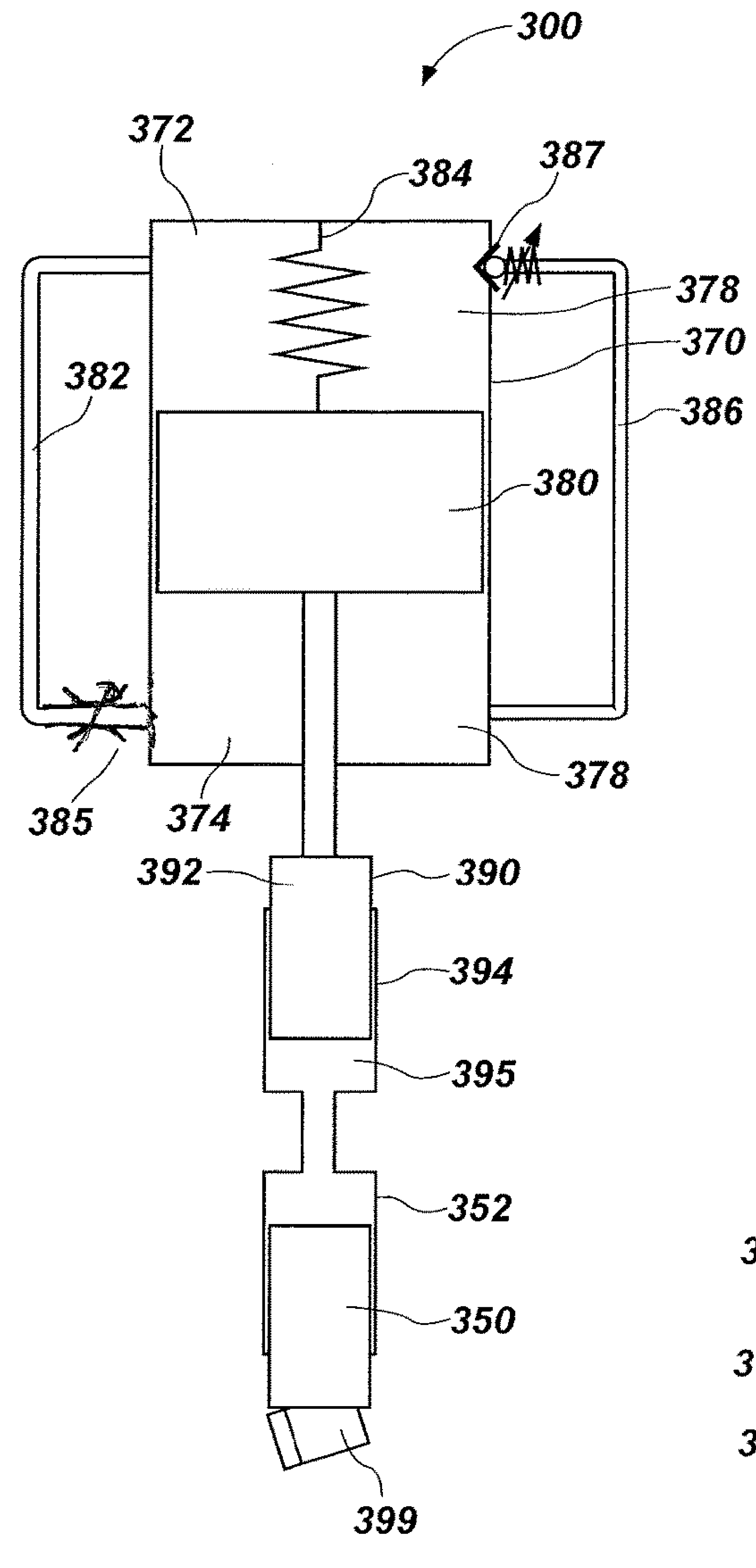
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FIG. 3

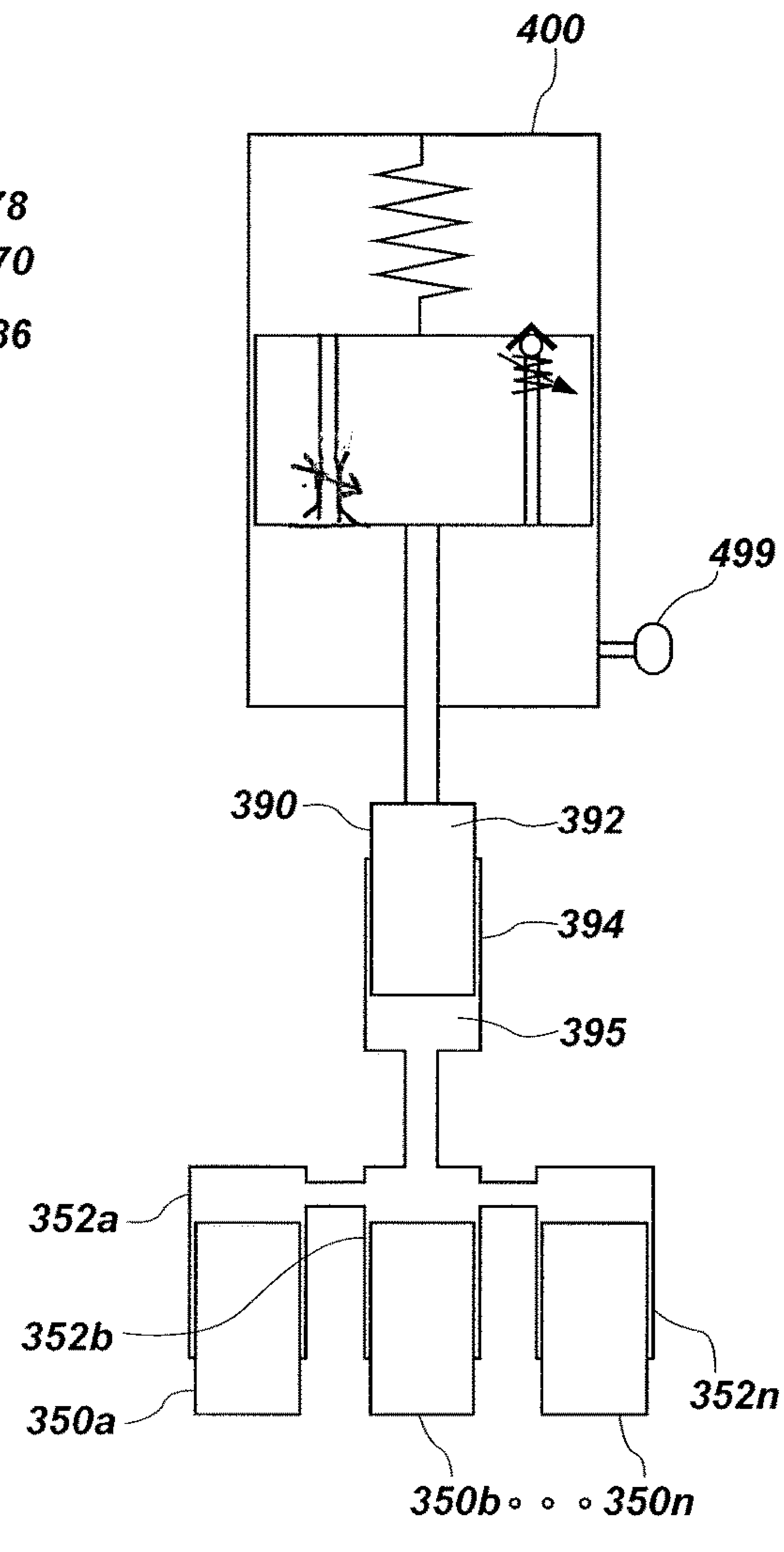
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FIG. 4

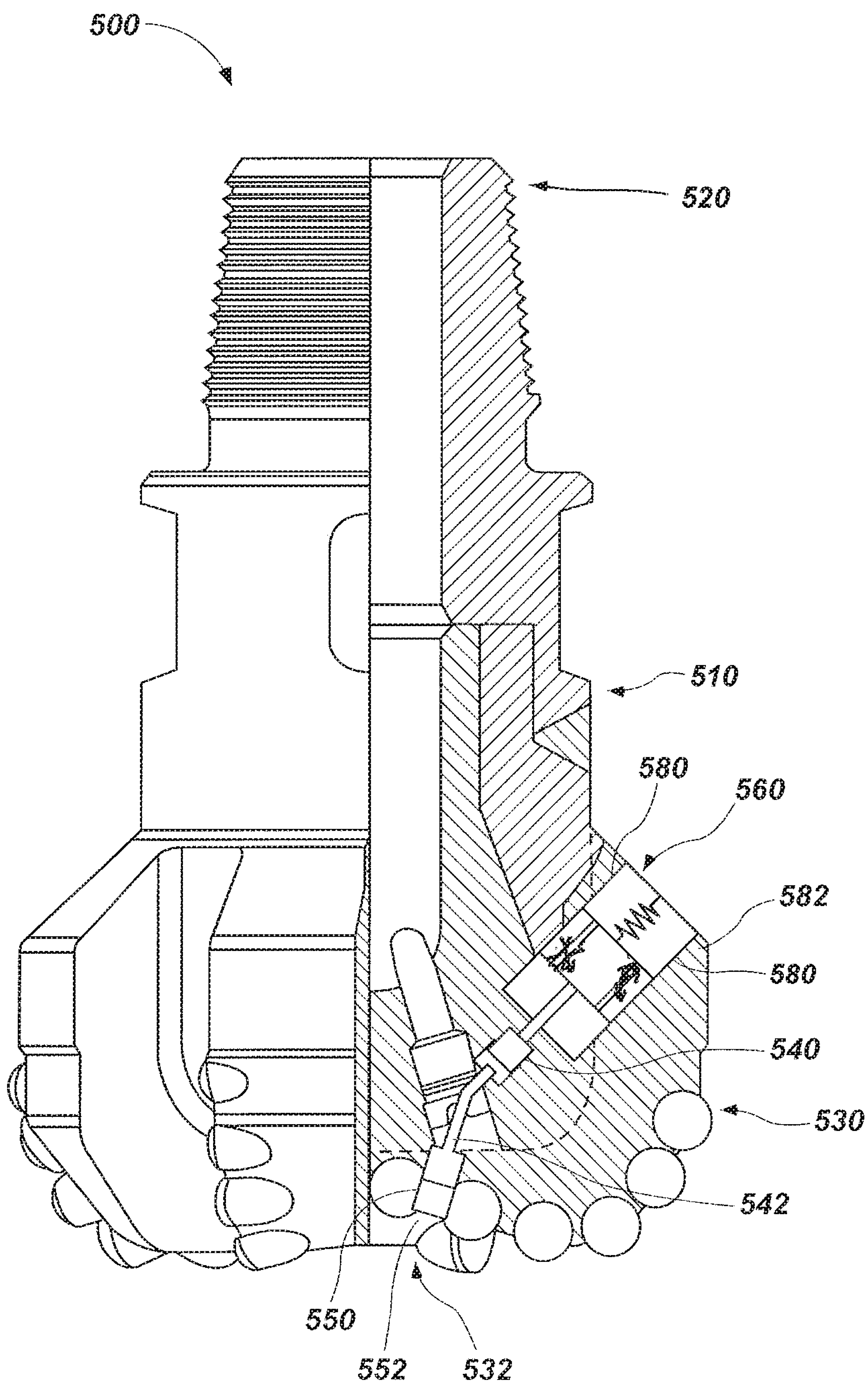


FIG. 5

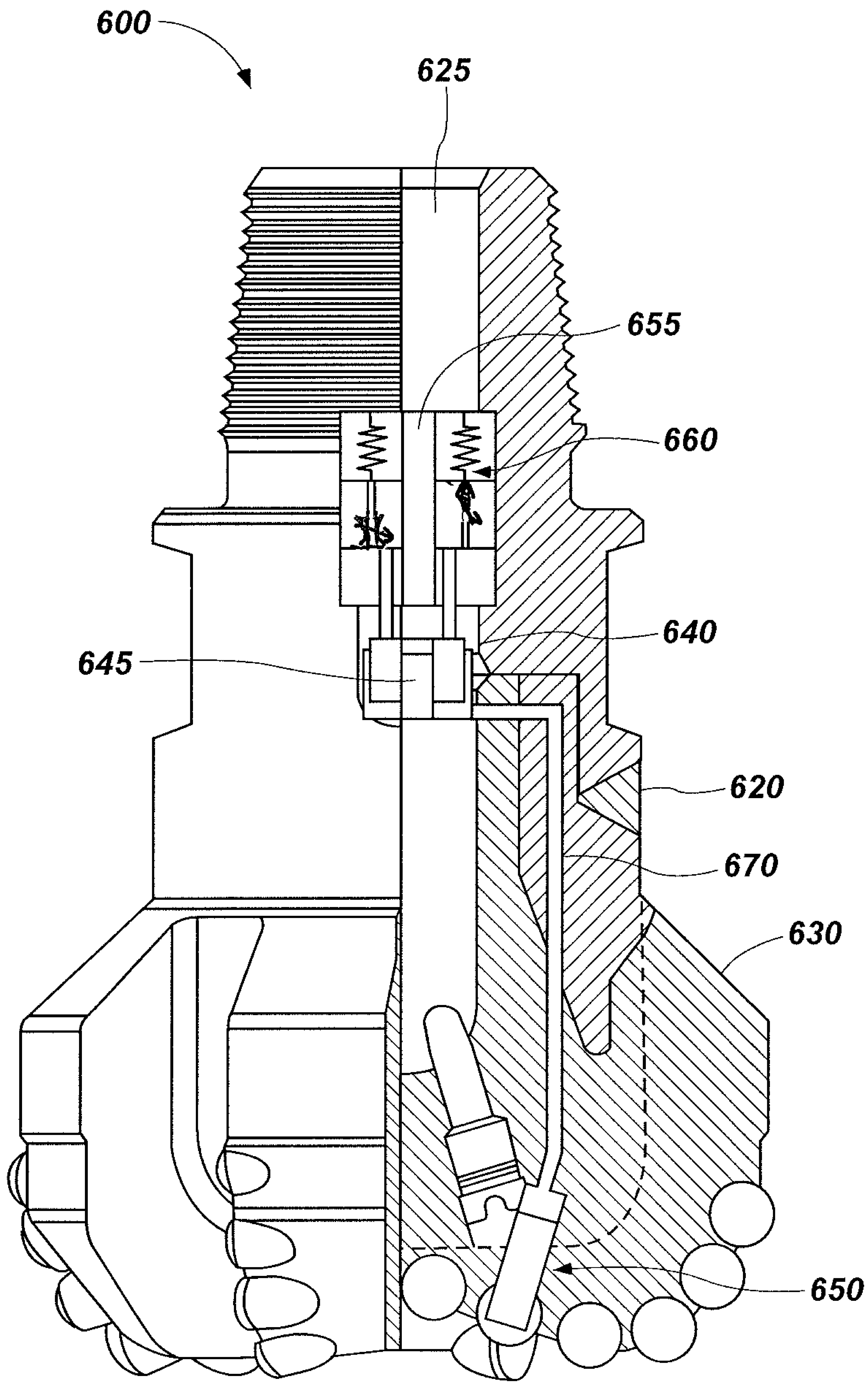


FIG. 6

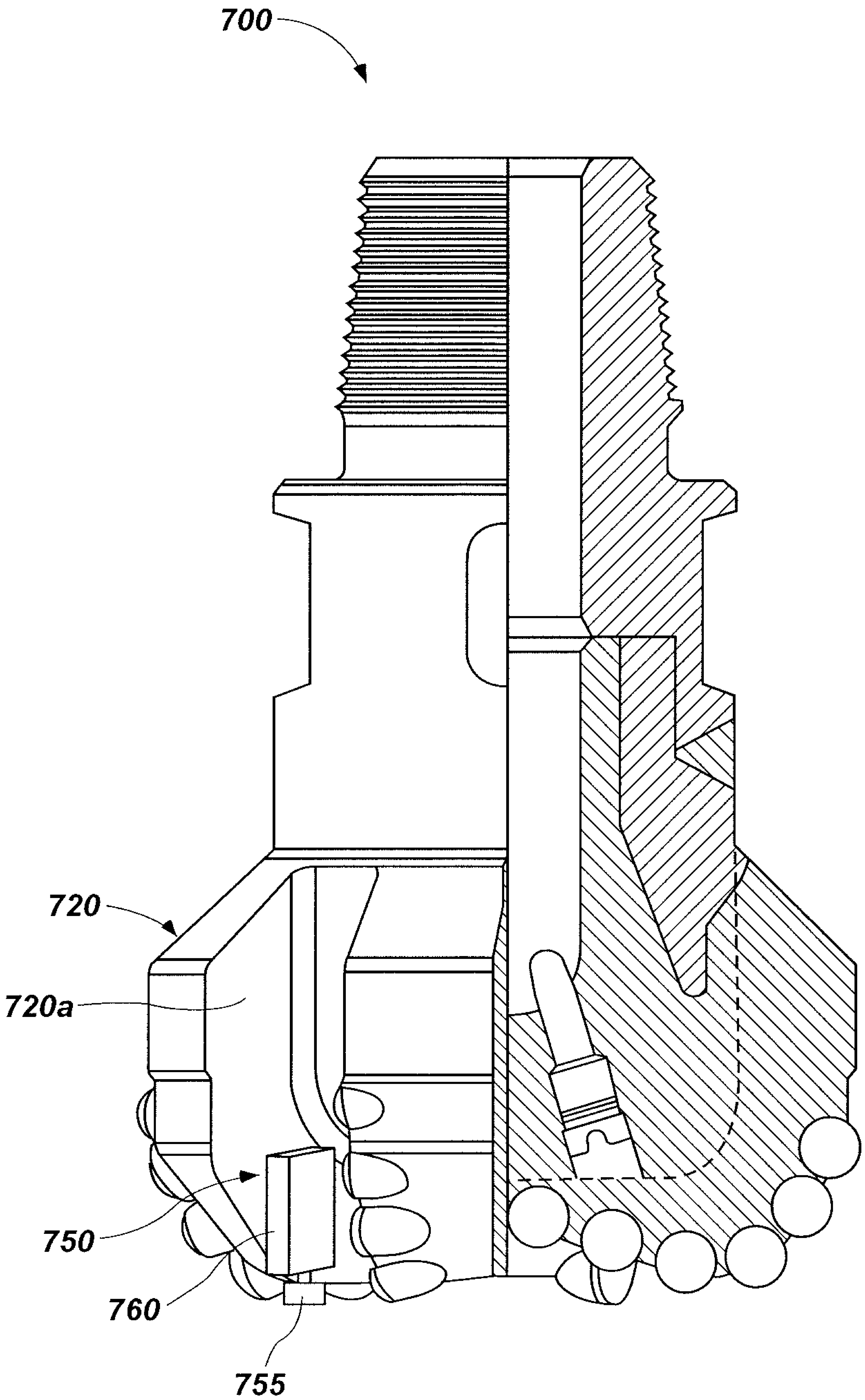


FIG. 7

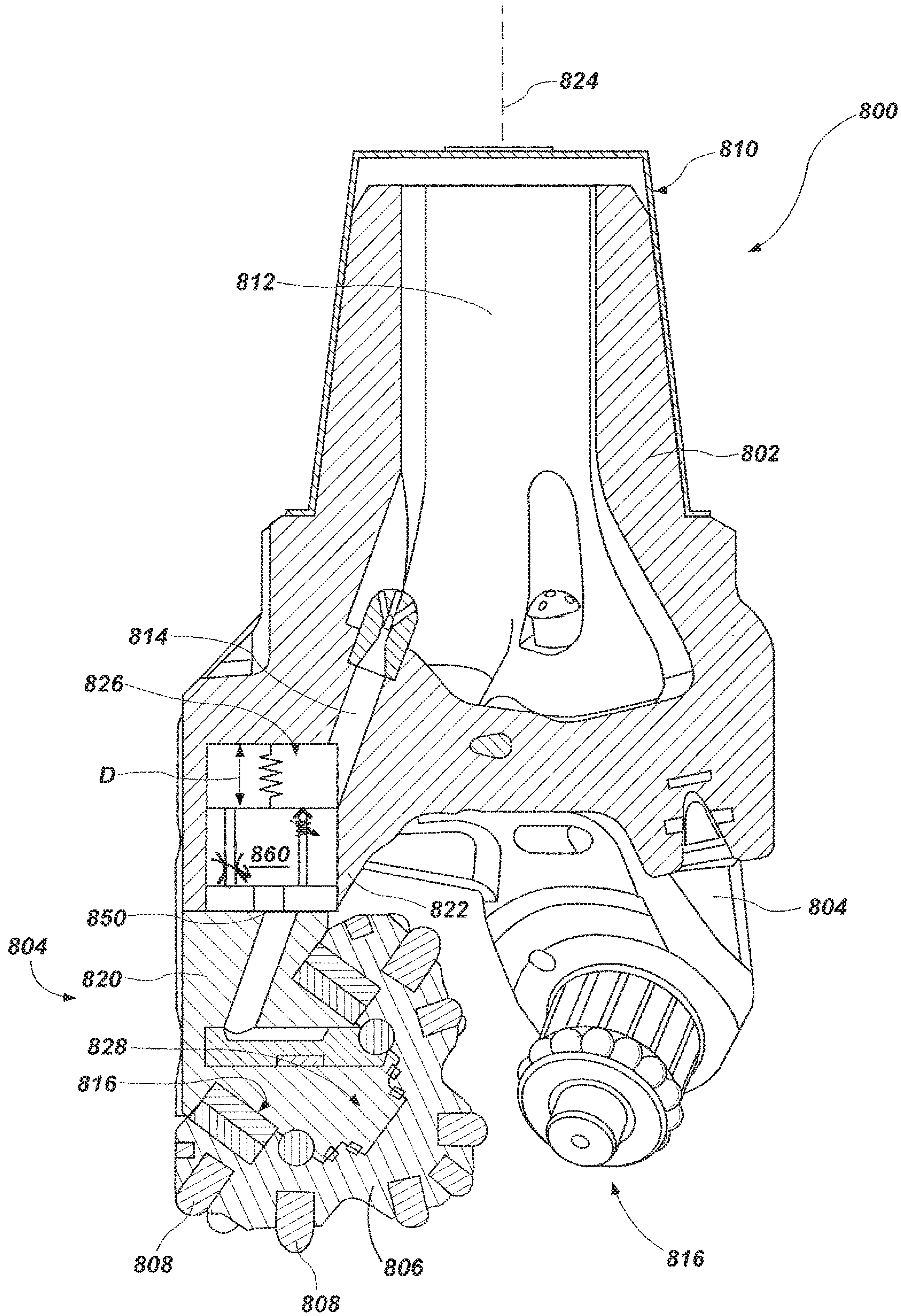

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FIG. 8

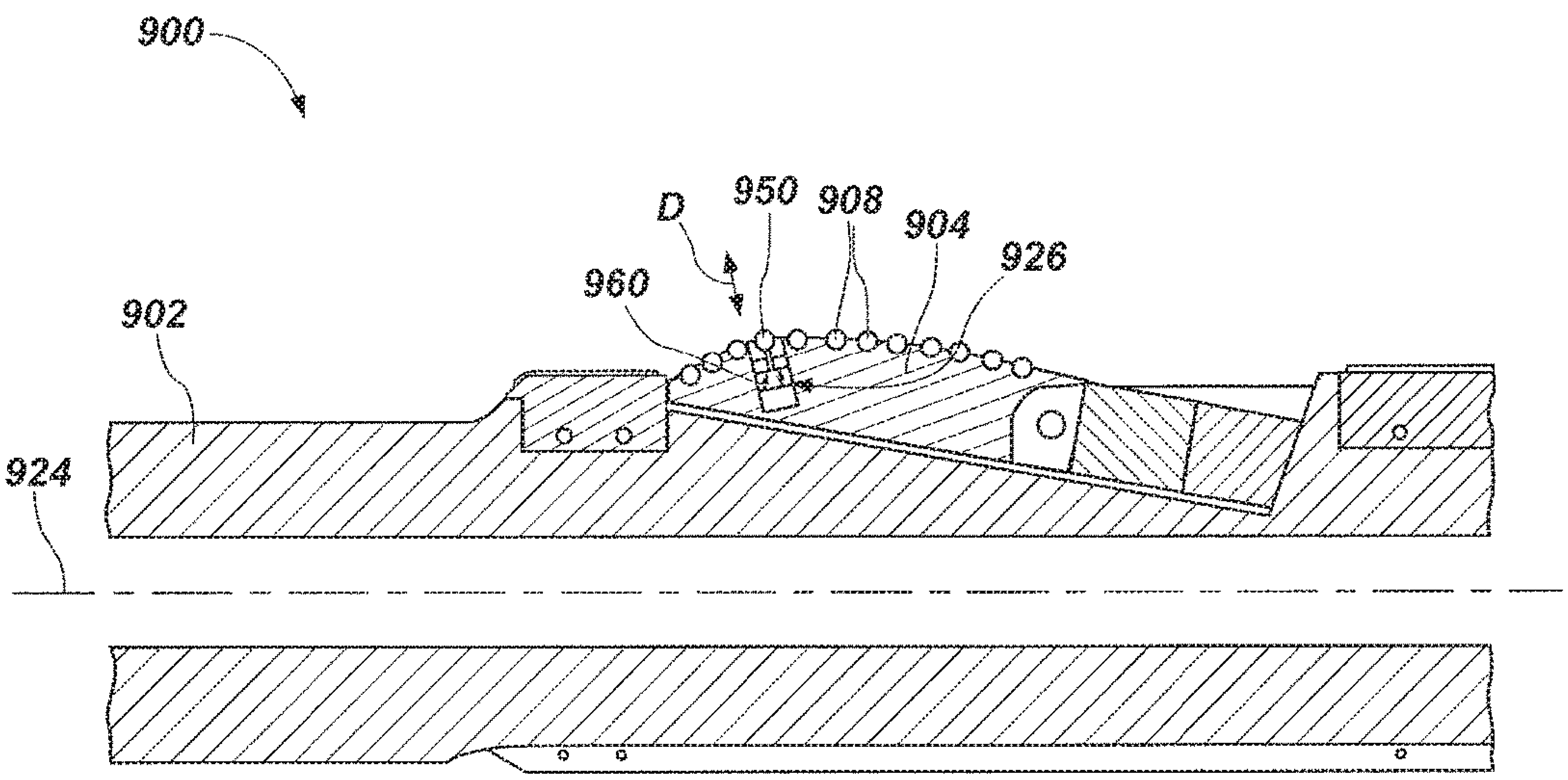


FIG. 9

# EARTH-BORING TOOLS INCLUDING PASSIVELY ADJUSTABLE, AGGRESSIVENESS-MODIFYING MEMBERS AND RELATED METHODS

## CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U.S. patent application Ser. No. 13/864,926, filed Apr. 17, 2013, now U.S. Pat. No. 9,255,450, issued Feb. 9, 2016, for "DRILL BIT WITH SELF-ADJUSTING PADS," the disclosure of which is incorporated herein in its entirety by this reference.

The subject matter of this application is related to U.S. patent application Ser. No. 14/851,117, filed Sep. 11, 2015, now U.S. Pat. No. 10,041,305, issued Aug. 7, 2018, and to U.S. patent application Ser. No. 14/972,635, filed Dec. 17, 2015, pending.

## FIELD

This disclosure relates generally to earth-boring tools and systems that utilize the same for drilling boreholes in earth formations. More specifically, disclosed embodiments relate to earth-boring tools that may include one or more passively adjustable, aggressiveness-modifying members configured to modify the aggressiveness of the earth-boring tools in response to forces acting on the passively adjustable, aggressiveness-modifying members.

## BACKGROUND

Oil wells (also referred to as "wellbores" or "boreholes") are drilled with a drill string that includes a tubular member having a drilling assembly (also referred to as the "bottomhole assembly" or "BHA"). The BHA typically includes devices and sensors that provide information relating to a variety of parameters relating to the drilling operations ("drilling parameters"), behavior of the BHA ("BHA parameters") and parameters relating to the formation surrounding the wellbore ("formation parameters"). An earth-boring tool, such as a drill bit attached to the bottom end of the BHA, is rotated by rotating the drill string and/or by a drilling motor (also referred to as a "mud motor") in the BHA to disintegrate the rock formation to drill the wellbore. A large number of wellbores are drilled along contoured trajectories. For example, a single wellbore may include one or more vertical sections, deviated sections and horizontal sections through differing types of rock formations. When drilling progresses from a soft formation, such as sand, to a hard formation, such as shale, or vice versa, the rate of penetration (ROP) of the drill changes and can cause (decreases or increases) excessive fluctuations or vibration (lateral or torsional) in the earth-boring tool. The ROP is typically controlled by controlling the weight-on-bit (WOB) and rotational speed (revolutions per minute or "RPM") of the drill bit so as to control drill bit fluctuations. The WOB is controlled by controlling the hook load at the surface and the RPM is controlled by controlling the drill string rotation at the surface and/or by controlling the drilling motor speed in the BHA. Controlling the drill bit fluctuations and ROP by such methods requires the drilling system or operator to take actions at the surface. The impact of such surface actions on the drill bit fluctuations is not substantially immediate. Drill bit aggressiveness contributes to the vibration, whirl and stick-slip for a given WOB and drill bit rotational speed. "Depth of Cut" (DOC) of a drill bit, generally defined as "the



distance the drill bit advances along axially into the formation in one revolution," is a contributing factor relating to the drill bit aggressiveness. Controlling DOC, cutting element exposure, and other aggressiveness-affecting parameters can provide a smoother borehole, avoid premature damage to the cutters and prolong operating life of the earth-boring tool.

## BRIEF SUMMARY

The disclosure herein provides a drill bit and drilling systems using the same configured to control the rate of change of instantaneous aggressiveness of an earth-boring tool during drilling of a wellbore.

In some embodiments, earth-boring tools may include a body and a passively adjustable, aggressiveness-modifying member secured to the body. The passively adjustable, aggressiveness-modifying member may be movable between a first position in which the earth-boring tool exhibits a first aggressiveness and a second position in which the earth-boring tool exhibits a second, different aggressiveness responsive to forces acting on the passively adjustable, aggressiveness-modifying member.

In other embodiments, methods of passively adjusting aggressivenesses of earth-boring tools may involve causing a force to be exerted on a passively adjustable, aggressiveness-modifying member secured to a body. The passively adjustable, aggressiveness-modifying member may move from a first position in which the earth-boring tool exhibits a first aggressiveness to a second position in which the earth-boring tool exhibits a second, different aggressiveness responsive to the force acting on the passively adjustable, aggressiveness-modifying member.

## BRIEF DESCRIPTION OF THE DRAWINGS

While this disclosure concludes with claims particularly pointing out and distinctly claiming specific embodiments, various features and advantages of embodiments within the scope of this disclosure may be more readily ascertained from the following description when read in conjunction with the accompanying drawings, in which:

FIG. **1** is a schematic diagram of an illustrative drilling system that includes a drill string that has an earth-boring tool made according to one embodiment of this disclosure;

FIG. **2** shows a partially cut-away side view of an illustrative earth-boring tool configured as a fixed-cutter drill bit with a passively adjustable, aggressiveness-modifying member and a rate control device for controlling the rates of extending and retracting the passively adjustable, aggressiveness-modifying member from a surface of the earth-boring tool, according to one embodiment of this disclosure;

FIG. **3** shows an alternative embodiment of the rate control device that operates the passively adjustable, aggressiveness-modifying member via a hydraulic line;

FIG. **4** shows an embodiment of a rate control device configured to operate multiple passively adjustable, aggressiveness-modifying members;

FIG. **5** shows placement of a rate control device of FIG. **4** in the crown section of the earth-boring tool;

FIG. **6** shows placement of a rate control device of in a fluid passage or flow path of the earth-boring tool;

FIG. **7** shows a drill bit, wherein the rate control device and the passively adjustable, aggressiveness-modifying member are placed on an outside surface of the earth-boring tool;

FIG. **8** is a cross-sectional view of another embodiment of an earth-boring tool configured as a rolling cone drill bit including a passively adjustable, aggressiveness-modifying member; and

FIG. **9** is a cross-sectional view of a portion of another embodiment of an earth-boring tool configured as an expandable reamer including a passively adjustable, aggressiveness-modifying member.

## DETAILED DESCRIPTION

The illustrations presented in this disclosure are not meant to be actual views of any particular drill string, earth-boring tool, or component thereof, but are merely idealized representations employed to describe illustrative embodiments. Thus, the drawings are not necessarily to scale.

Disclosed embodiments relate generally to earth-boring tools that may include one or more passively adjustable, aggressiveness-modifying members configured to modify the aggressiveness of the earth-boring tools in response to forces acting on the passively adjustable, aggressiveness-modifying members. More specifically, disclosed are embodiments of earth-boring tools that may enable selective increasing and decreasing of the aggressiveness of the earth-boring tools utilizing the forces acting on, and corresponding responsive movement of, passively adjustable, aggressiveness-modifying members secured to the earth-boring tools.

Although some embodiments of passively adjustable, aggressiveness-modifying members in this disclosure are depicted as being used and employed in earth-boring drill bits, such as fixed-cutter earth-boring rotary drill bits, sometimes referred to as "drag" bits, and rolling-cone drill bits, and earth-boring reamers, such as expandable reamers, passively adjustable, aggressiveness-modifying members in accordance with this disclosure may be employed in any earth-boring tool having a cutting structure susceptible to passive adjustment of its aggressiveness. Accordingly, the terms "earth-boring tool" and "earth-boring drill bit," as used in this disclosure, mean and include any type of bit or tool used for drilling during the formation or enlargement of a wellbore in a subterranean formation and include, for example, fixed-cutter drill bits, rolling cone bits, percussion bits, core bits, eccentric bits, bicenter bits, reamers, mills, hybrid bits, and other drilling bits and tools known in the art.

As used in this disclosure, the term "passive" when used in the context of the adjustment of an aggressiveness-modifying member means and includes embodiments wherein the adjustment is achieved without requiring any special-purpose, dedicated electrical or electromechanical actuation components to accomplish adjustment. For example, passively adjustable, aggressiveness-modifying members may lack electronic and electromechanical actuation mechanisms and may not require dedicated operator triggers (e.g., changing flow rates of circulating fluid, changing rates of rotation of the drill string, making such changes in a predetermined pattern) to accomplish or initiate adjustment. As an additional example, passively adjustable, aggressiveness-modifying members may be actuatable utilizing mechanical or hydraulic actuation mechanisms, and may automatically actuate, deactuate, and otherwise modify aggressiveness in response to forces inherently acting on the passively adjustable, aggressiveness-modifying members during use.

As used in this disclosure, the term "aggressiveness" (μ) of an earth-boring tool is calculated according to the following formula:

$$\mu = \frac{36 \times T}{D \times W}$$

wherein T is the torque applied to the earth-boring tool, D is the diameter of the earth-boring tool, and W is the weight applied to the earth-boring tool (e.g., weight-on-bit (WOB)). Aggressiveness is a unitless number. Aggressiveness may be affected by factors such as vibration, number of blades or cones, cutting element size, type, and configuration, hardness of the subterranean formation, etc. These factors may affect the aggressiveness by changing the torque delivered at a particular applied weight. Different types of earth-boring tools may exhibit different aggressivenesses. As illustrative examples, conventional roller cone bits may have a bit aggressiveness of from about 0.10 to about 0.25, impregnated bits may have a bit aggressiveness of from about 0.12 to about 0.40, and fixed-cutter bits may have a bit aggressiveness of from about 0.40 to about 1.50 (assuming, in each case, similar cutting element type on each blade or roller cone of a bit, and somewhat evenly distributed applied weight between each blade or roller cone). Hybrid bits (bits having a combination of roller cones and fixed-cutter blades) may have a bit aggressiveness between that of a roller cone bit and a fixed-cutter drill bit.

FIG. **1** is a schematic diagram of an illustrative drilling system **100** that may utilize earth-boring tools made according to the disclosure herein. FIG. **1** shows a wellbore **110** having an upper section **111** with a casing **112** installed therein and a lower section **114** being drilled with a drill string **118**. The drill string **118** is shown to include a tubular member **116** with a BHA **130** attached at its bottom end. The tubular member **116** may be made up by joining drill pipe sections or it may be a coiled-tubing. An earth-boring tool **150** is shown attached to the bottom end of the BHA **130** for disintegrating the rock formation **119** to drill the wellbore **110** of a selected diameter.

Drill string **118** is shown conveyed into the wellbore **110** by a rig **180** at the surface **167**. The illustrative rig **180** shown is a land rig for ease of explanation. The apparatus and methods disclosed herein may also be utilized with an offshore rig used for drilling wellbores under water. A rotary table **169** or a top drive (not shown) coupled to the drill string **118** may be utilized to rotate the drill string **118** to rotate the BHA **130** and thus the earth-boring tool **150** to drill the wellbore **110**. A drilling motor **155** (also referred to as the "mud motor") may be provided in the BHA **130** to rotate the earth-boring tool **150**. The drilling motor **155** may be used alone to rotate the earth-boring tool **150** or to superimpose the rotation of the earth-boring tool **150** by the drill string **118**. A control unit (or controller) **190**, which may be a computer-based unit, may be placed at the surface **167** to receive and process data transmitted by the sensors in the earth-boring tool **150** and the sensors in the BHA **130**, and to control selected operations of the various devices and sensors in the BHA **130**. The surface controller **190**, in one embodiment, may include a processor **192**, a data storage device (or a computer-readable medium) **194** for storing data, algorithms and computer programs **196**. The data storage device **194** may be any suitable device, including, but not limited to, a read-only memory (ROM), a random-access memory (RAM), a flash memory, a magnetic tape, a hard disk and an optical disk. During drilling, a drilling fluid **179** from a source thereof is pumped under pressure into the tubular member **116**. The drilling fluid discharges at the bottom of the earth-boring tool **150** and returns to the surface via the annular space (also referred as the "annulus") between the drill string **118** and the inside wall **142** of the wellbore **110**.

The BHA **130** may further include one or more downhole sensors (collectively designated by numeral **175**). The sensors **175** may include any number and type of sensors, including, but not limited to, sensors generally known as the measurement-while-drilling (MWD) sensors or the logging-while-drilling (LWD) sensors, and sensors that provide information relating to the behavior of the BHA **130**, such as drill bit rotation (revolutions per minute or "RPM"), tool face, pressure, vibration, whirl, bending, and stick-slip. The BHA **130** may further include a control unit (or controller) **170** that controls the operation of one or more devices and sensors in the BHA **130**. The controller **170** may include, among other things, circuits to process the signals from sensor **175**, a processor **172** (such as a microprocessor) to process the digitized signals, a data storage device **174** (such as a solid-state-memory), and a computer program **176**. The processor **172** may process the digitized signals, and control downhole devices and sensors, and communicate data information with the controller **190** via a two-way telemetry unit **188**.

Still referring to FIG. **1**, the earth-boring tool **150** may include a face section (or bottom section) **152**. The face section **152** or a portion thereof faces the formation in front of the earth-boring tool **150** or the wellbore bottom during drilling. The earth-boring tool **150**, in one aspect, includes one or more passively adjustable, aggressiveness-modifying members **160** that may be extended and retracted from a selected surface of the earth-boring tool **150** to passively adjust an aggressiveness of the earth-boring tool **150**. The passively adjustable, aggressiveness-modifying members **160** may also be referred to as "pads," "extensible pads," "extendable pads," "adjustable pads," "adjustable gage pads," "adjustable cutting elements," "adjustable cutters," "adjustable inserts," "adjustable ovoids," "adjustable legs," and "adjustable depth-of-cut controlling devices," depending on where they are located, which type of earth-boring tool they are secured to, and the particular configuration they employ. A suitable actuation device (or actuation unit) **165** in the earth-boring tool **150** may be utilized to extend and retract one or more passively adjustable, aggressiveness-modifying members **160** from a surface of the earth-boring tool **150** during drilling (e.g., formation or enlargement) of the wellbore **110**. In one aspect, the actuation device **165** may control the rate of extension and retraction of the passively adjustable, aggressiveness-modifying members **160**. The actuation device **165** is also referred to as a "rate control device" or "rate controller." In another aspect, the actuation device **165** is a passive device that automatically adjusts or self-adjusts the extension and retraction of the passively adjustable, aggressiveness-modifying members **160** based on, or in response to, the force or pressure applied to the passively adjustable, aggressiveness-modifying members **160** during drilling. The rate of extension and retraction of the passively adjustable, aggressiveness-modifying members **160** may be preset as described in more detail in reference to FIGS. **2** through **4**.

FIG. **2** shows an illustrative earth-boring tool **200** made according to one embodiment of this disclosure. The earth-boring tool **200** is a polycrystalline diamond compact (PDC), fixed-cutter bit having a body **201** that includes a neck or neck section **210**, a shank **220**, and a crown or crown section **230**. The neck **210** has a tapered upper end **212** having threads **212***a* thereon for connecting the earth-boring tool **200** to a box end of the drilling assembly **130** (FIG. **1**). The shank **220** has a lower vertical or straight section **222** that is fixedly connected to the crown **230** at a joint **224**. The crown **230** includes a face or face section **232** that faces the formation during drilling. The crown **230** includes a number of blades, such as blades **234***a*, **234***b*, etc. A typical PDC bit may include, for example, from three to seven blades. Each blade has a face (also referred to as a "face section") and a side (also referred to as a "side section"). For example, blade **234***a* has a face **232***a* and a side **236***a*, while blade **234***b* has a face **232***b* and a side **236***b*. The sides **236***a* and **236***b* extend along the longitudinal or vertical axis **202** (e.g., an axis of rotation) of the earth-boring tool **200**. Each blade further may further include a number of cutters secured thereto. In the particular embodiment of FIG. **2**, blade **234***a* is shown to include cutters **238***a* on a portion of the side **236***a* and cutters **238***b* along the face **232***a* while blade **234***b* is shown to include cutters **239***a* on the side **236***b* and cutters **239***b* on the face **232***b*.

Still referring to FIG. **2**, the earth-boring tool **200** includes one or more passively adjustable, aggressiveness-modifying members **250** that extend and retract from a surface **252** of the earth-boring tool **200**. FIG. **2** shows a passively adjustable, aggressiveness-modifying member **250** movably placed in a cavity or recess **254** in the crown section **230**. As shown in FIG. **2**, the passively adjustable, aggressiveness-modifying member **250** may be configured as, for example, a pad or depth-of-cut control device configured to modify a depth of cut of the cutters **238**. An activation device **260** may be coupled to the passively adjustable, aggressiveness-modifying member **250** to extend and retract the passively adjustable, aggressiveness-modifying member **250** from a surface location **252** on the earth-boring tool **200**.

In one aspect, the activation device **260** controls the rate of extension and retraction of the passively adjustable, aggressiveness-modifying member **250**. In another aspect, the device **260** extends the passively adjustable, aggressiveness-modifying member **250** at a first rate and retracts the passively adjustable, aggressiveness-modifying member **250** at a second rate. In embodiments, the first rate and second rate may be the same or different rates. In another aspect, the rate of extension of the passively adjustable, aggressiveness-modifying member **250** may be greater than the rate of retraction As noted above, the device **260** also is referred to herein as a "rate control device" or a "rate controller." In the particular embodiment of the device **260**, the passively adjustable, aggressiveness-modifying member **250** is directly coupled to the device **260** via a mechanical connection or connecting member **256**.

In one aspect, the device **260** includes a chamber **270** that houses a double acting reciprocating member, such as a piston **280**, that sealingly divides the chamber **270** into a first chamber **272** and a second chamber **274**. Both chambers **272** and **274** are filled with a hydraulic fluid **278** suitable for downhole use, such as oil. A biasing member, such as a spring **284**, in the first chamber **272**, applies a selected force on the piston **280** to cause it to move outward. Since the piston **280** is connected to the passively adjustable, aggressiveness-modifying member **250**, moving the piston outward causes the passively adjustable, aggressiveness-modifying member **250** to extend from the surface **252** of the earth-boring tool **200**. In one aspect, the chambers **272** and **274** are in fluid communication with each other via a first fluid flow path or flow line **282** and a second fluid flow path or flow line **286**. A flow control device, such as a flow restrictor **285** (e.g., an orifice plate), a check valve, or a flow restrictor **285** and a check valve, placed in the fluid flow line **282**, may be utilized to control the rate of flow of the fluid from chamber **274** to chamber **272**. Similarly, another flow control device, such as a check valve **287**, a flow restrictor, or a check valve **287** and a flow restrictor, placed in fluid flow line **286**, may be utilized to control the rate of flow of the fluid **278** from chamber **272** to chamber **274**. The flow control devices **285** and **287** may be configured at the surface to set the rates of flow through fluid flow lines **282** and **286**, respectively.

In one aspect, one or both flow control devices **285** and **287** may include a variable control, biasing device, such as a spring, to provide a constant flow rate from one chamber to another. Constant fluid flow rate exchange between the chambers **272** and **274** provides a first constant rate for the extension for the piston **280** and a second constant rate for the retraction of the piston **280** and, thus, corresponding constant rates for extension and retraction of the passively adjustable, aggressiveness-modifying member **250**. The size of the flow control lines **282** and **286** along with the setting of their corresponding biasing devices **285** and **287** define the flow rates through lines **282** and **286**, respectively, and thus the corresponding rate of extension and retraction of the passively adjustable, aggressiveness-modifying member **250**. In one aspect, the fluid flow line **282** and its corresponding flow control device **285** may be set such that when the earth-boring tool **200** is not in use, i.e., there is no external force being applied onto the passively adjustable, aggressiveness-modifying member **250**, the biasing member **284** will extend the passively adjustable, aggressiveness-modifying member **250** to the maximum extended position. In one aspect, the flow control line **282** may be configured so that the biasing member **284** extends the passively adjustable, aggressiveness-modifying member **250** relatively fast or suddenly. When the earth-boring tool **200** is in operation, such as during drilling of a wellbore, the weight applied to the earth-boring tool **200** may exert an external force on the passively adjustable, aggressiveness-modifying member **250**. This external force may cause the passively adjustable, aggressiveness-modifying member **250** to apply a force or pressure on the piston **280** and thus on the biasing member **284**.

In one aspect, the fluid flow line **286** may be configured to allow relatively slow flow rate of the fluid from chamber **272** into chamber **274**, thereby causing the passively adjustable, aggressiveness-modifying member **250** to retract relatively slowly. As an example, the extension rate of the passively adjustable, aggressiveness-modifying member **250** may be set so that the passively adjustable, aggressiveness-modifying member **250** extends from the fully retracted position to a fully extended position over a few seconds while it retracts from the fully extended position to the fully retracted position over one or several minutes or longer (such as, for example, between two and five minutes). It will be noted that any suitable rate may be set for the extension and retraction of the passively adjustable, aggressiveness-modifying member **250**. In one aspect, the device **260** is a passive device that adjusts the extension and retraction of a passively adjustable, aggressiveness-modifying member **250** based on or in response to the force or pressure applied on the passively adjustable, aggressiveness-modifying member **250**.

When the passively adjustable, aggressiveness-modifying member **250** is in a first state, the earth-boring tool **200** may exhibit a first aggressiveness, and the earth-boring tool **200** may exhibit a second, different aggressiveness when the passively adjustable, aggressiveness-modifying member **250** is in a second state. For example, when the passively adjustable, aggressiveness-modifying member **250** is in a fully extended position, the earth-boring tool **200** may exhibit a least aggressiveness, and the earth-boring tool may exhibit a greatest aggressiveness when the passively adjustable, aggressiveness-modifying member **250** is in a fully retracted position. Moreover, the passively adjustable, aggressiveness-modifying member **250** may automatically adapt the aggressiveness of the earth-boring tool **200** responsive to forces inherently acting on the passively adjustable, aggressiveness-modifying member **250** (e.g., applied weight, vibrational forces, reaction forces from the formation, applied torque) to and between the greatest and least aggressivenesses, enabling the earth-boring tool **200** to adaptively react to drilling conditions without requiring active intervention from an operator or complex, active adjustment-controlling mechanisms.

The passively adjustable, aggressiveness-modifying member **250** may enable the earth-boring tool **200** to effectively drill the earth formation at lower applied torque for a given applied weight (e.g., weight on bit (WOB)). For example, the passively adjustable, aggressiveness-modifying member **250** may enable a 5% reduction in applied torque for a given applied weight or more. More specifically, the passively adjustable, aggressiveness-modifying member **250** may enable, for example, a 10% reduction in applied torque for a given applied weight or more. As specific, nonlimiting examples, the passively adjustable, aggressiveness-modifying member **250** may enable a 15%, 25%, 30%, 50%, or 60% reduction in applied torque for a given applied weight or more.

FIG. **3** shows an another embodiment of a rate control device **300**. The device **300** includes a fluid chamber **370** divided by a double acting piston **380** into a first chamber **372** and a second chamber **374**. The chambers **372** and **374** are filled with a hydraulic fluid **378**. A first fluid flow line **382** and an associated flow control device **385** allow the fluid **378** to flow from chamber **374** to chamber **372** at a first flow rate and a fluid flow line **386** and an associated flow control device **387** allow the fluid **378** to flow from the chamber **372** to chamber **374** at a second rate. The piston **380** is connected to a force transfer device **390** that includes a piston **392** in a chamber **394**. The chamber **394** contains a hydraulic fluid **395**, which is in fluid communication with a passively adjustable, aggressiveness-modifying member **350**. In one aspect, the passively adjustable, aggressiveness-modifying member **350** may be placed in a chamber **352**, which chamber is in fluid communication with the fluid **395** in chamber **394**. When the biasing device **384** moves the piston **380** outward, it moves the piston **392** outward and into the chamber **394**. Piston **392** expels fluid **395** from chamber **394** into the chamber **352**, which extends the passively adjustable, aggressiveness-modifying member **350**. When a force is applied on to the passively adjustable, aggressiveness-modifying member **350**, it pushes the fluid from chamber **352** into chamber **394**, which applies a force onto the piston **380**. The rate of the movement of the piston **380** is controlled by the flow of the fluid through the fluid flow line **386** and flow control device **387**.

In the particular configuration shown in FIG. **3**, the rate control device **300** is not directly connected to the passively adjustable, aggressiveness-modifying member **350**, which enables isolation of the device **300** from the passively adjustable, aggressiveness-modifying member **350** and allows it to be located at any desired location in the earth-boring tool, as described in connection with FIGS. **5** and **6**. In another aspect, the passively adjustable, aggressiveness-modifying member **350** may be directly connected to a cutter **399** or an end of the passively adjustable, aggressiveness-modifying member **350** may be made as a cutter. In this configuration, the cutter **399** acts both as a cutter and an extendable and a retractable, passively adjustable, aggressiveness-modifying member **350**.

FIG. **4** shows a shared rate control device **400** configured to operate more than one passively adjustable, aggressiveness-modifying member, such as passively adjustable, aggressiveness-modifying members **350***a*, **350***b*, . . . **350***n*. The rate control device **400** is the same as shown and described in FIG. **2**, except that it is shown to apply force onto the passively adjustable, aggressiveness-modifying members **350***a*, **350***b*, . . . **350***n* via an intermediate device **390**, as shown and described in reference to FIG. **3**. In the embodiment of FIG. **4**, each of the passively adjustable, aggressiveness-modifying members **350***a*, **350***b* . . . **350***n* is housed in separate chambers **352***a*, **352***b* . . . **352***n*, respectively. The fluid **395** from chamber **394** is supplied to all chambers **352***a*, **352***b* . . . **352***n*, thereby automatically and simultaneously extending and retracting each of the passively adjustable, aggressiveness-modifying members **350***a*, **350***b* . . . **350***n* based on external forces applied to each such passively adjustable, aggressiveness-modifying members **350***a*, **350***b* . . . **350***n* during drilling. In aspects, the rate control device **400** may include a suitable pressure compensator **499** for downhole use. Similarly any of the rate controllers made according to any of the embodiments may employ a suitable pressure compensator.

FIG. **5** shows an isometric view of an earth-boring tool **500**, wherein a rate control device **560** is placed in a crown section **530** of the earth-boring tool **500**. The rate control device **560** is the same as shown in FIG. **2**, but is coupled to a passively adjustable, aggressiveness-modifying member **550** via a hydraulic connection **540** and a fluid line **542**. The rate control device **560** is shown placed in a recess **580** accessible from an outside surface **582** of the crown section **530**. The passively adjustable, aggressiveness-modifying member **550** is shown placed at a face location section **552** on the face **532**, while the hydraulic connection **540** is shown placed in the crown section **530** between the passively adjustable, aggressiveness-modifying member **550** and the rate control device **560**. It should be noted that the rate control device **560** may be placed at any desired location in the earth-boring tool **500**, including in the shank **520** and neck section **510** and the hydraulic line **542** may be routed in any desired manner from the rate control device **560** to the passively adjustable, aggressiveness-modifying member **550**. Such a configuration provides flexibility of placing the rate control device **560** substantially anywhere in the earth-boring tool **500**.

FIG. **6** shows an isometric view of a earth-boring tool **600**, wherein a rate control device **660** is placed in a fluid passage **625** of the earth-boring tool **600**. In the particular tool configuration of FIG. **6**, the hydraulic connection **640** is placed proximate the rate control device **660**. A hydraulic line **670** is run from the hydraulic connection **640** to the passively adjustable, aggressiveness-modifying member **650** through the shank **620** and the crown **630** of the earth-boring tool **600**. During drilling, a drilling fluid flows through the passage **625**. To enable the drilling fluid to flow freely through the passage **625**, the rate control device **660** may be provided with a through bore or passage **655** and the hydraulic connection device **640** may be provided with a flow passage **645**.

FIG. **7** shows an earth-boring tool **700**, wherein an integrated passively adjustable, aggressiveness-modifying member **755** and rate control device **750** is placed on an outside surface of the earth-boring tool **700**. In one aspect, the device **750** includes a rate control device **760** connected to a passively adjustable, aggressiveness-modifying member **755**. In one aspect, the device **750** is a sealed unit that may be attached to any outside surface of the earth-boring tool **700**. The rate control device **760** may be the same as or different from the rate control devices described herein in connection with FIGS. **2** through **6**. In the particular embodiment of FIG. **7**, the passively adjustable, aggressiveness-modifying member **755** is shown connected to a side **720***a* of a blade **720** of the earth-boring tool **700**. The device **750** may be attached or placed at any other suitable location in the earth-boring tool **700**. Alternatively or in addition thereto, the device **750** may be integrated into a blade so that the passively adjustable, aggressiveness-modifying member **755** will extend toward a desired direction from the earth-boring tool **700**.

FIG. **8** is a cross-sectional view of another embodiment of an earth-boring tool **800** including a passively adjustable, aggressiveness-modifying member **850**. The earth-boring tool **800**, depicted as a roller cone bit, includes a body **802** having three legs **804** depending from the body **802**. A roller cone **806** is rotatably mounted to a bearing pin **816** on each of the legs **804**. Each roller cone **806** may comprise a plurality of cutters **808** (e.g., teeth or inserts) thereon. The earth-boring tool **800** includes a threaded section **810** at its upper end for connection a drill string **118** (see FIG. **1**). The earth-boring tool **800** may include an internal plenum **812** extending through the body **802** to fluid passageways **814** that extend from the plenum **812** to a bearing system **828** enabling the roller cones **806** to rotate about the bearing pin **816** as they engage with an underlying earth formation.

The passively adjustable, aggressiveness modifying member **850** may be integrated into one or more of the legs **804** of the earth-boring tool **800**, such that each leg **804** including a passively adjustable, aggressiveness modifying member **850** may be movable with respect to the body **802**. For example, the passively adjustable, aggressiveness modifying member **850** may include a bottom portion **820** of the leg **804**, proximate the bearing pin **816** and separated from the body **802** by an upper portion **822** of the leg **804**. The bottom portion **820** of the leg **804** may be movable in a direction D at least substantially parallel to a longitudinal axis **824** (e.g., an axis of rotation) of the earth-boring tool **800**. The upper portion **822** of the leg **804** may include a recess **826** extending into the leg **804** toward the body **802**, the recess **826** being sized and shaped to receive a rate control device **860** therein. The rate control device **860** may be the same as, or different from, the rate control devices described herein in connection with FIGS. **2** through **7**.

When the earth-boring tool **800** is deployed in a borehole, the passively adjustable, aggressiveness modifying member **850** may move between a first, fully extended state and a second, fully retracted state in response to forces acting on the passively adjustable, aggressiveness modifying member **850**. For example, the passively adjustable, aggressiveness modifying member **850** may dampen vibrations experienced by the earth-boring tool **800** by moving between a first, lowest longitudinal position along the longitudinal axis **824** and second, highest longitudinal position along the longitudinal axis **824**, dampening vibration experienced by the earth-boring tool **800**.

FIG. **9** is a cross-sectional view of a portion of another embodiment of an earth-boring tool **900** including a passively adjustable, aggressiveness-modifying member **950**. The earth-boring tool **900**, depicted in FIG. **9** as an expandable reamer, may include sliding blades **904** positionally retained in a circumferentially spaced relationship in a generally cylindrical tubular body **902** of the earth-boring tool. Each blade **904** may include cutters **908** secured thereto, the cutters **908** being configured to engage with, and remove earth material from, a sidewall of a borehole. The blades **904** are movable relative to the tubular body **902** during use of the earth-boring tool **900** between a retracted position and an extended position responsive to application of hydraulic pressure.

The passively adjustable, aggressiveness modifying member **950** may be configured as one or more of the cutters **908** (e.g., PDC cutting elements, impregnated inserts, or inserts of wear resistant material (e.g., metal-matrix-cemented tungsten carbide)) of the earth-boring tool **900**. A passively adjustable, aggressiveness modifying member **950** may be included on each blade **904** in some embodiments. In other embodiments, a passively adjustable, aggressiveness-modifying member may be secured to fewer than all blades **904** of the earth-boring tool **900**. The passively adjustable, aggressiveness modifying member **950** may be movable in a direction D oriented perpendicular to, or at an oblique angle relative to, a longitudinal axis **924** (e.g., an axis of rotation) of the earth-boring tool **900**. The blade **904** may include a recess **926** extending into the blade **904** toward the body **902**, the recess **926** being sized and shaped to receive a rate control device **960** therein. The rate control device **960** may be the same as, or different from, the rate control devices described herein in connection with FIGS. **2** through **8**.

When the earth-boring tool **900** is deployed in a borehole, the passively adjustable, aggressiveness modifying member **950** may move between a first, fully extended state and a second, fully retracted state in response to forces acting on the passively adjustable, aggressiveness modifying member **950**. For example, the passively adjustable, aggressiveness modifying member **950** may transition between an overexposed and an underexposed state relative to the other cutters **908** by moving between a first, outermost radial position from the longitudinal axis **924** and second, innermost radial position from the longitudinal axis **924**, responsive to lateral forces from the sidewall of the borehole.

Thus, in various embodiments, a rate controller may be a hydraulic actuation device and may be placed at any desired location in the earth-boring tool or outside the earth-boring tool to self-adjust extension and retraction of one or more passively adjustable, aggressiveness-modifying members based on or in response to external forces applied on the passively adjustable, aggressiveness-modifying members during drilling of a wellbore. The passively adjustable, aggressiveness-modifying members may be located and oriented independently from the location and/or orientation of the rate controller in the earth-boring tool. Multiple passively adjustable, aggressiveness-modifying members may be inter-connected and activated simultaneously. Multiple passively adjustable, aggressiveness-modifying members may also be connected to a shared rate controller.

In various embodiments, during stick-slip, the passively adjustable, aggressiveness-modifying members can extend relatively quickly at high rotational speed (RPM) of the earth-boring tool when the depth of cut (DOC) of the cutters is low. However, at low RPM, when the DOC starts increasing suddenly, the pads resist sudden inward motion and create a large contact (rubbing) force preventing high DOC. Limiting high DOC during stick-slip reduces the high torque build-up and mitigates stick-slip. In various embodiments, the rate controller may allow sudden or substantially sudden extension (outward motion) of a passively adjustable, aggressiveness-modifying member and limit sudden retraction (inward motion) of the passively adjustable, aggressiveness-modifying member. Such a mechanism may prevent sudden increase in the depth of cut of cutters during drilling. A pressure compensator may be provided to balance the pressures inside and outside the cylinder of the rate controller.

Additional, nonlimiting embodiments within the scope of this disclosure follow:

### Embodiment 1

An earth-boring tool, comprising: a body; and a passively adjustable, aggressiveness-modifying member secured to the body, the passively adjustable, aggressiveness-modifying member being movable between a first position in which the earth-boring tool exhibits a first aggressiveness and a second position in which the earth-boring tool exhibits a second, different aggressiveness responsive to forces acting on the passively adjustable, aggressiveness-modifying member.

### Embodiment 2

The earth-boring tool of Embodiment 1, wherein the passively adjustable, aggressiveness-modifying member comprises one of a depth-of-cut limiting device, a cutting element, a pad, an ovoid, and a leg having a rolling cone secured to an end of the leg and wherein the passively adjustable, aggressiveness modifying member is movable from the first position at a first longitudinal and radial position relative to an outer surface of the body to the second position at a second, different longitudinal position, radial position, or both longitudinal and radial position relative to the outer surface of the body.

### Embodiment 3

The earth-boring tool of Embodiment 1 or Embodiment 2, wherein the first position corresponds to an extended state, the second position corresponds to a retracted state, the passively adjustable, aggressiveness-modifying member is movable toward the first position at a first rate, and the passively adjustable, aggressiveness-modifying member is movable toward the second position at a second, slower rate.

### Embodiment 4

The earth-boring tool of Embodiment 3, wherein the passively adjustable, aggressiveness-modifying member is biased toward the first position.

### Embodiment 5

The earth-boring tool of Embodiment 3 or Embodiment 4, wherein the passively adjustable, aggressiveness-modifying member comprises: a formation-engaging structure; a piston operatively connected to the formation-engaging structure, the piston positioned to apply a force on the pad; a biasing member applying a force on the piston toward the first position; a fluid chamber divided by the piston into a first fluid chamber and a second fluid chamber; and a first fluid flow path from the first fluid chamber to the second fluid chamber that controls movement of the piston toward the first position at the first rate and a second fluid flow path from the second chamber to the first chamber that controls movement of the piston toward the second position at the second rate.

Embodiment 6

The earth-boring tool of Embodiment 5, wherein a first check valve, first flow restrictor, or first check valve and first flow restrictor in the first fluid flow path defines the first rate and a second check valve, second flow restrictor, or second check valve and second flow restrictor in the second fluid flow path defines the second rate.

Embodiment 7

The earth-boring tool of Embodiment 5 or Embodiment 6, wherein the piston comprises a double-acting piston and a fluid acting on a first side of the double-acting piston controls at least in part the first rate and a fluid acting on a second, opposite side of the double-acting piston controls at least in part the second rate.

Embodiment 8

The earth-boring tool of any one of Embodiments 5 through 7, wherein the piston is operatively coupled to the formation-engaging structure by one of: a direct mechanical connection and via a fluid.

Embodiment 9

The earth-boring tool of any one of Embodiments 1 through 8, wherein the earth-boring tool is a rolling cone drill bit or a hybrid bit and the passively adjustable, aggressiveness-modifying member is located on a leg extending from the body of the rolling cone drill bit or hybrid bit toward a rolling cone secured to an end of the leg, the passively adjustable, aggressiveness-modifying member enabling the leg to dampen vibration as the rolling cone engages with an underlying earth formation.

Embodiment 10

The earth-boring tool of Embodiment 9, further comprising an additional passively adjustable, aggressiveness-modifying member on each other leg extending from the body of the rolling cone drill bit or hybrid bit.

Embodiment 11

The earth-boring tool of any one of Embodiments 1 through 8, wherein the earth-boring tool is a reamer and the passively adjustable, aggressiveness-modifying member is located on a blade of the reamer, the passively adjustable, aggressiveness-modifying member being configured to modify a depth of cut of cutting elements secured to the blade of the reamer in response to forces applied to the passively adjustable, aggressiveness-modifying member as the cutting elements engage with an earth formation.

Embodiment 12

The earth-boring tool of Embodiment 11, further comprising an additional passively adjustable, aggressiveness-modifying member on each other blade of the reamer.

Embodiment 13

A method of passively adjusting an aggressiveness of an earth-boring tool, comprising: causing a force to be exerted on a passively adjustable, aggressiveness-modifying member secured to a body; and moving the passively adjustable, aggressiveness-modifying member from a first position in which the earth-boring tool exhibits a first aggressiveness to a second position in which the earth-boring tool exhibits a second, different aggressiveness responsive to causing the force to act on the passively adjustable, aggressiveness-modifying member.



Embodiment 14

The method of Embodiment 13, wherein moving the passively adjustable, aggressiveness-modifying member from the first position to the second position comprises increasing the aggressiveness of the earth-boring tool by retracting the passively adjustable, aggressiveness-modifying member from an extended position, toward the body, to a retracted position.

Embodiment 15

The method of Embodiment 14, further comprising subsequently decreasing the aggressiveness of the earth-boring tool by extending the passively adjustable, aggressiveness-modifying member from the retracted position, away from the body, to the extended position.

Embodiment 16

The method of Embodiment 15, wherein retracting the passively adjustable, aggressiveness-modifying member from the extended position to the retracted position comprises retracting the passively adjustable, aggressiveness-modifying member from the extended position to the retracted position at a first rate and wherein extending the passively adjustable, aggressiveness-modifying member from the retracted position to the extended position comprises extending the passively adjustable, aggressiveness-modifying member from the retracted position to the extended position at a second, faster rate.

Embodiment 17

The method of Embodiment 15 or Embodiment 16, wherein extending the passively adjustable, aggressiveness-modifying member from the retracted position to the extended position comprises enabling a biasing member biasing the passively adjustable, aggressiveness-modifying member toward the extended position to extend the passively adjustable, aggressiveness-modifying member from the retracted position to the extended position.

Embodiment 18

The method of any one of Embodiments 13 through 17, wherein the passively adjustable, aggressiveness-modifying member comprises one of a depth-of-cut limiting device, a cutting element, a pad, an ovoid, and a leg having a rolling cone secured to an end of the leg and wherein moving the passively adjustable, aggressiveness-modifying member from the first position to the second position comprises moving the passively adjustable, aggressiveness modifying member from a first longitudinal and radial position relative to an outer surface of the body to a second, different longitudinal position, radial position, or both longitudinal and radial position relative to the outer surface of the body.

Embodiment 19

The method of any one of Embodiments 13 through 18, wherein the earth-boring tool is a rolling cone drill bit or a hybrid bit and the passively adjustable, aggressiveness-modifying member is located on a leg extending from the body of the rolling cone drill bit or hybrid bit toward a rolling cone secured to an end of the leg, and wherein moving the passively adjustable, aggressiveness-modifying member from the first position to the second position comprises dampening vibration experienced by the leg as the rolling cone engages with an underlying earth formation.

Embodiment 20

The method of any one of Embodiments 13 through 18, wherein the earth-boring tool is a reamer and the passively adjustable, aggressiveness-modifying member is located on a blade of the reamer, and wherein moving the passively adjustable, aggressiveness-modifying member from the first position to the second position comprises modifying a depth of cut of cutting elements secured to the blade of the reamer in response to forces applied to the passively adjustable, aggressiveness-modifying member as the cutting elements engage with an earth formation.

While certain illustrative embodiments have been described in connection with the figures, those of ordinary skill in the art will recognize and appreciate that the scope of this disclosure is not limited to those embodiments explicitly shown and described in this disclosure. Rather, many additions, deletions, and modifications to the embodiments described in this disclosure may be made to produce embodiments within the scope of this disclosure, such as those specifically claimed, including legal equivalents. In addition, features from one disclosed embodiment may be combined with features of another disclosed embodiment while still being within the scope of this disclosure, as contemplated by the inventors.

What is claimed is:

**1**. An earth-boring reamer, comprising:

a blade; and

a passively adjustable, aggressiveness-modifying member located on the blade, the passively adjustable, aggressiveness-modifying member being movable between a first position in which the reamer exhibits a first aggressiveness and a second position in which the reamer exhibits a second, different aggressiveness responsive to forces acting on the passively adjustable, aggressiveness-modifying member, the passively adjustable, aggressiveness-modifying member configured to modify a depth of cut of cutting elements secured to the blade of the reamer in response to forces applied to the passively adjustable aggressiveness-modifying member as the cutting elements engage with an earth formation.

**2**. The reamer of claim **1**, wherein the passively adjustable, aggressiveness-modifying member comprises one of a depth-of-cut limiting device, a cutting element, a pad, or an ovoid, and wherein the passively adjustable, aggressiveness modifying member is movable from the first position at a first longitudinal and radial position relative to an outer surface of the blade to the second position at a second, different longitudinal position, radial position, or both longitudinal and radial position relative to the outer surface of the blade.

**3**. The reamer of claim **1**, wherein the first position corresponds to an extended state, the second position corresponds to a retracted state, the passively adjustable, aggressiveness-modifying member is movable toward the first position at a first rate, and the passively adjustable, aggressiveness-modifying member is movable toward the second position at a second, slower rate.



**4**. The reamer of claim **3**, wherein the passively adjustable, aggressiveness-modifying member is biased toward the first position.

**5**. The reamer of claim **3**, wherein the passively adjustable, aggressiveness-modifying member comprises:

a formation-engaging structure;

a piston operatively connected to the formation-engaging structure, the piston positioned to apply a force on the pad;

a biasing member applying a force on the piston toward the first position;

a fluid chamber divided by the piston into a first fluid chamber and a second fluid chamber; and

a first fluid flow path from the first fluid chamber to the second fluid chamber that controls movement of the piston toward the first position at the first rate and a second fluid flow path from the second chamber to the first chamber that controls movement of the piston toward the second position at the second rate.

**6**. The reamer of claim **5**, wherein a first check valve, first flow restrictor, or first check valve and first flow restrictor in the first fluid flow path defines the first rate and a second check valve, second flow restrictor, or second check valve and second flow restrictor in the second fluid flow path defines the second rate.

**7**. The reamer of claim **5**, wherein the piston comprises a double-acting piston and a fluid acting on a first side of the double-acting piston controls at least in part the first rate and a fluid acting on a second, opposite side of the double-acting piston controls at least in part the second rate.

**8**. The reamer of claim **5**, wherein the piston is operatively coupled to the formation-engaging structure by one of: a direct mechanical connection and via a fluid.

**9**. The reamer of claim **1**, further comprising a rolling cone drill bit or a hybrid bit operatively connected to the reamer, the rolling cone drill bit or the hybrid bit comprising another passively adjustable, aggressiveness-modifying member located on a leg extending from a body of the rolling cone drill bit or the hybrid bit toward a rolling cone secured to an end of the leg, the other passively adjustable, aggressiveness-modifying member enabling the leg to dampen vibration as the rolling cone engages with an underlying earth formation.

**10**. The reamer of claim **9**, wherein the rolling cone drill bit further comprises one or more other legs and further comprising an additional passively adjustable, aggressiveness-modifying member on each other leg extending from the body of the rolling cone drill bit or hybrid bit.

**11**. The reamer of claim **1**, wherein the reamer further comprises one or more other blades and further comprising an additional passively adjustable, aggressiveness-modifying member on each other blade of the reamer.

**12**. A method of passively adjusting an aggressiveness of a reamer, comprising:

causing a force to be exerted on a passively adjustable, aggressiveness-modifying member secured to a blade; and

moving the passively adjustable, aggressiveness-modifying member from a first position in which the reamer exhibits a first aggressiveness to a second position in which the reamer exhibits a second, different aggressiveness responsive to causing the force to act on the passively adjustable, aggressiveness-modifying member by modifying a depth of cut of cutting elements secured to the blade of the reamer in response to forces applied to the passively adjustable, aggressiveness-modifying member as the cutting elements engage with an earth formation.

**13**. The method of claim **12**, wherein moving the passively adjustable, aggressiveness-modifying member from the first position to the second position comprises increasing the aggressiveness of the reamer by retracting the passively adjustable, aggressiveness-modifying member from an extended position, toward the body, to a retracted position.

**14**. The method of claim **13**, further comprising subsequently decreasing the aggressiveness of the reamer by extending the passively adjustable, aggressiveness-modifying member from the retracted position, away from the blade, to the extended position.

**15**. The method of claim **14**, wherein retracting the passively adjustable, aggressiveness-modifying member from the extended position to the retracted position comprises retracting the passively adjustable, aggressiveness-modifying member from the extended position to the retracted position at a first rate and wherein extending the passively adjustable, aggressiveness-modifying member from the retracted position to the extended position comprises extending the passively adjustable, aggressiveness-modifying member from the retracted position to the extended position at a second, faster rate.

**16**. The method of claim **14**, wherein extending the passively adjustable, aggressiveness-modifying member from the retracted position to the extended position comprises using biasing member biasing the passively adjustable, aggressiveness-modifying member toward the extended position to extend the passively adjustable, aggressiveness-modifying member from the retracted position to the extended position.

**17**. The method of claim **12**, wherein the passively adjustable, aggressiveness-modifying member comprises one of a depth-of-cut limiting device, a cutting element, a pad, or an ovoid and wherein moving the passively adjustable, aggressiveness-modifying member from the first position to the second position comprises moving the passively adjustable, aggressiveness modifying member from a first longitudinal and radial position relative to an outer surface of the blade to a second, different longitudinal position, radial position, or both longitudinal and radial position relative to the outer surface of the blade.

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UNITED STATES PATENT AND TRADEMARK OFFICE

# CERTIFICATE OF CORRECTION



PATENT NO. : 10,094,174 B2
APPLICATION NO. : 14/973282
DATED : October 9, 2018
INVENTOR(S) : Jayesh Rameshlal Jain et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims

Claim 16, Column 18, Line 6, change "using biasing member" to --using a biasing member--

Signed and Sealed this
Eleventh Day of June, 2019

Andrei Iancu
*Director of the United States Patent and Trademark Office*